USDA

ted States
partment of
iculture

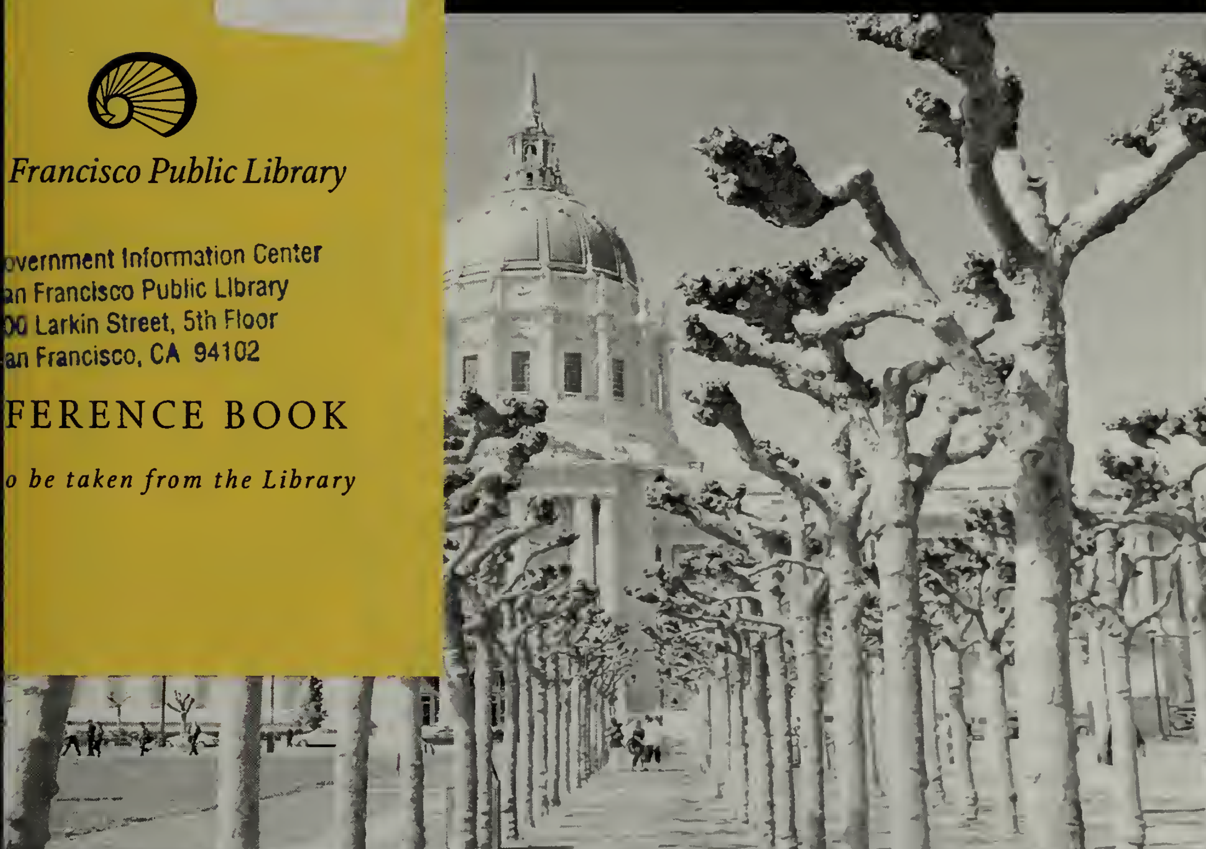
est Service

rtheastern
earch Station

neral Technical
ort

Assessing Urban Forest Effects and Values

sco's Urban Forest



UFORE
Urban Forest Effects Model

Northeastern Research Station
USDA Forest Service

USDA

United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

General Technical
Report

Assessing Urban Forest Effects and Values

San Francisco's Urban Forest

UFORE
Urban Forest Effects Model

Northeastern Research Station
USDA Forest Service

Published by:

USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

September 2005

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740) 368-0152

UFORE
Urban Forest Effects Model

There are many benefits to having trees and vegetation in an urban environment. In addition to aesthetic appeal and cultural importance, trees in cities can contribute significantly to human health and environmental quality. To help understand the urban forest resource better and its numerous values, the USDA Forest Service, Northeastern Research Station, developed the Urban Forest Effects (UFORE) model. This model has been applied to many cities across the United States and internationally as well. Results from this model can be extrapolated to characterize San Francisco's total tree population. This model includes data for trees in both public and private properties. In addition to measuring overhead canopy and shrub cover at various sites, the model also estimates ground cover and land-use. Looking at the amalgam of these factors can advance urban forest understanding and management to improve human health and environmental quality in urban places.

This report presents findings of the UFORE analysis for the City of San Francisco, California.

Contributors to this report are:

David J. Nowak, USDA Forest Service
Robert E. Hoehn III, USDA Forest Service
Alexis Harte, San Francisco Department of the Environment
Jack C. Stevens, USDA Forest Service
Jeffrey T. Walton, USDA Forest Service
Daniel E. Crane, USDA Forest Service
Leslie Bandy, Surveyor Coordinator

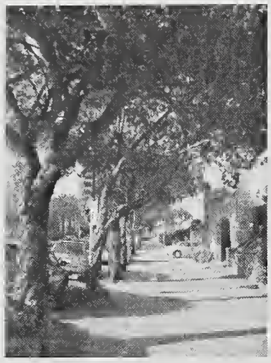
Surveyors:
- Karin Avila
- Sarah Cobey
- Maria D'agostino
- Rachel Freund
- Meleana Judd
- Lorraine Maldague
- Jennifer Mar
- Kelly Palomera

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

For more information on this project, please contact:

David J. Nowak
USDA Forest Service
dnowak@fs.fed.us
(315) 448-3200

Alexis Harte
San Francisco Department of the Environment
Alexis.Harte@sfgov.org
(415) 355-3764



San Francisco's urban forest provides numerous benefits for the city, yet we have just begun to study and understand this important resource.

Calculated environmental benefits of the urban forest are significant, yet many environmental and social benefits remain to be quantified.

Executive Summary

Trees in urban areas along with other vegetation comprise the urban forest and provide many environmental benefits. Understanding an urban forest's structure, functions and values can improve future planning and management efforts to enhance urban tree health and optimize urban forest benefits to improve human health and environmental quality.

Forest structure is a measure of various physical attributes of the vegetation such as tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity; which make up the city's green infrastructure. Forest functions include a wide range of environmental and ecosystem services that trees and forests perform. These functions are directly related to the forest structure and environmental variables. Forest values are an estimate of the economic worth to society of various forest functions.

To help determine the vegetation structure, functions, and values of the urban forest in San Francisco, a vegetation assessment was conducted during the summer of 2004. For this assessment in San Francisco one-tenth acre field plots were sampled and analyzed using the Urban Forest Effects (UFORE) model[1]. The UFORE model was developed by the USDA Forest Service to simplify the process of conducting an analysis of the urban forest ecosystem and currently assesses forest structure and value, forest risk to various insect pests, and forest functions of air pollution removal and value; carbon storage, annual carbon removal (sequestration), and its value, which are important values in terms of global climate change and greenhouse effects due to the urban forest.

This report summarizes the basic elements of San Francisco forest structure, functions, and values. More detailed findings and methods can be found at: www.fs.fed.us/syracuse/data/data.htm.

Table 1. San Francisco urban forest summary

Feature	Measure
Number of trees	668,000
Tree cover	11.9%
Top 3 species	blue gum eucalyptus, Monterey pine, Monterey cypress
% of population <6" diameter	51.3%
Pollution removal	287 tons/year ($1.3 million/year)
Carbon storage	194,000 tons ($3.6 million)
Carbon sequestration	5,100 tons/year ($94,000/year)
Avoided carbon emissions	$16,000 / year
Structural values	$2 billion

Ton – short ton (U.S.) (2,000 lbs)

Urban Forest Effects model & field measurements

This section briefly outline the methods used to analyze the structure, functions, and values of the urban forest in San Francisco. Though urban forests provide many functions and values, only a few of these attributes can currently be assessed. To help assess the city's urban forest, data from 194 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model[1].

The UFORE model is designed to use standardized field data from randomly located plots, and local hourly air pollution and meteorological data to quantify urban forest structure and numerous urban forest effects, including[†]:

- Urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.).
- Hourly amount of pollution removed by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, and Dutch elm disease.

Field vegetation surveys were conducted using 1/10 acre plots randomly located based on land-use. The plots were divided among these land-use types: commercial/industrial (20 plots), institutional (10 plots), street/right-of-way (30 plots), openspace (65 plots), residential (58 plots), vacant (11 plots), which allows for comparison between the areas.

All field data collection was coordinated by San Francisco Department of the Environment's Urban Forest Program and San Francisco Friends of the Urban Forest[2] during the leaf-on season to properly assess tree canopies. Within each plot, data collected included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem-diameter at breast height (dbh, 4.5 ft.), tree height, height to base of the live crown, crown width, percent crown canopy missing and dieback[3].

† For more information go to http://www.ufore.org

Benefits provided by urban trees include:

- Air temperature reduction
- Air pollution removal
- Reduced building energy use
- Absorption of ultraviolet radiation
- Improved water quality
- Reduced noise
- Improved human comfort
- Wildlife habitat
- Increased property value
- Reduced stress
- Improved physiological & psychological well-being
- Aesthetics
- Community cohesion
- Improved human health

Plots in San Francisco were established throughout the city's 120 square miles by a random stratified sample.

To learn more about the methods[10] behind the UFORE analysis go to www.ufore.org

Field data gathered on trees throughout the city were combined with local hourly weather and pollution data to estimate various urban forest functions.

To calculate current carbon storage, biomass for each tree was calculated using allometric equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[4]. To adjust for this difference, biomass results for open-grown urban trees are multiplied by 0.8. No adjustment is made for trees found in natural stand conditions. Total tree dry-weight biomass was converted to total stored carbon by multiplying by 0.5. To estimate the gross amount carbon sequestered annually, average diameter growth from the appropriate genera group, diameter class, and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year $x+1$.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[5]. As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[6] that were adjusted depending upon leaf phenology and leaf area. Particulate removal incorporated a 50% resuspension rate of particles back to the atmosphere[7].

Compensatory values were determined based on valuation procedures of the Council of Tree and Landscape Appraisers[9], which uses tree species, diameter, condition and location information[10].

Field Survey Data

PLOT INFORMATION
- Land use type
- Percent tree cover
- Percent shrub cover
- Percent plantable space
- Percent ground cover types
- Shrub species / dimensions

TREE PARAMETERS
- Species
- Stem diameter
- Total height
- Height to crown base
- Crown width
- Percent foliage missing
- Percent dieback
- Crown light exposure

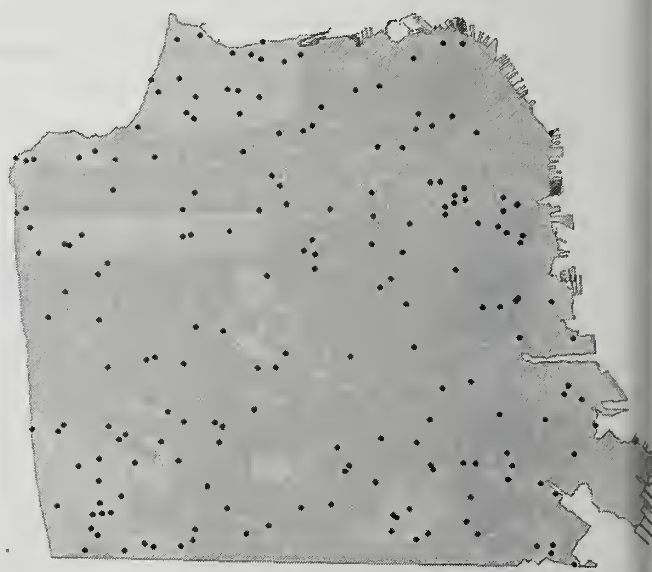


Figure 1. Data collected & plot distribution within land-use types of San Francisco

Tree characteristics of the urban forest

The urban forest of San Francisco is estimated to have 668,000 trees with an overall tree cover of 11.9%. Trees that have diameters less than six inches constitute slightly over fifty percent of the total population (51.3). The most common trees in the urban forest are blue gum eucalyptus (15.9%), Montery pine (8.4%), and Monterey cypress (3.8%).

Among the land-use types the highest density of trees occurs in openspace (36.9 trees per acre), followed by institutional (24.0 trees per acre) and street/right-of-way (23.7 trees per acre). The overall tree density in San Francisco is 22.5 trees per acre, which is comparable to other city tree densities (Appendix A) that range between 14.3 and 111.6 trees per acre.

Urban forests are mix of native trees species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus urban forests often a tree diversity that is higher than the surrounding native vegetation. While having an increased tree diversity can minimize the overall impact or destruction by a species specific insect or disease, the increase in the number of exotic plants can pose a risk to native plants if some of the exotics species are invasive plants that can potentially displace some native species. In San Francisco, approximately 80% of the species are native to North America, while 74% are native to the state. While species that are exotic to California make up 26% of the population, most exotic species are from Europe (29.3% of the population).

There are an estimated 668,000 trees in San Francisco with canopies that cover 11.9% of the city.

The top ten species account for 46% of the total number of trees.

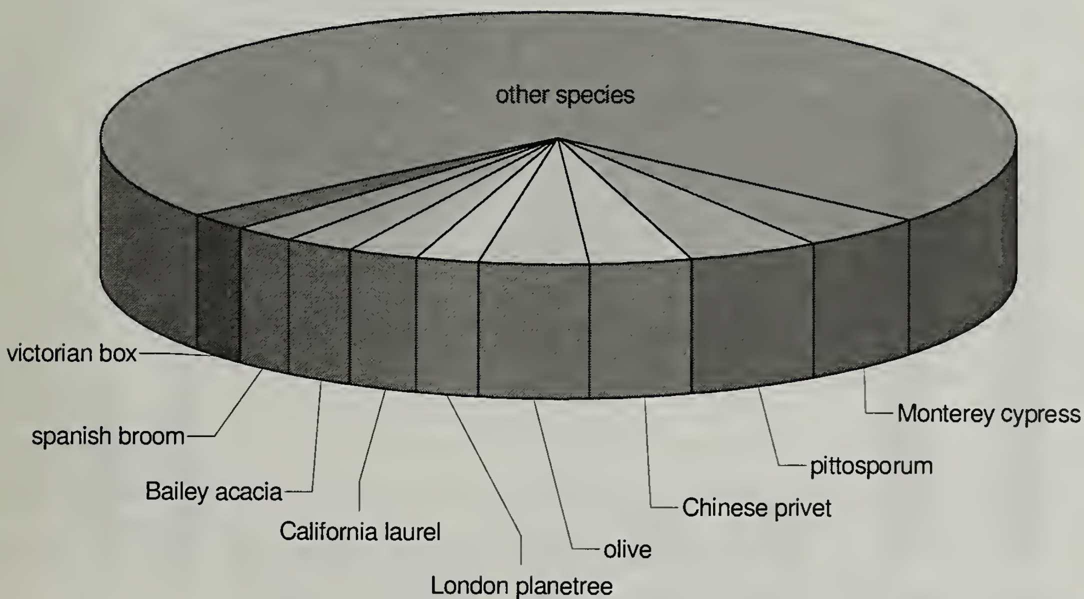


Figure 2. Species by percent of population

Nearly three quarters of the tree species found in San Francisco have native ranges within the state of California.

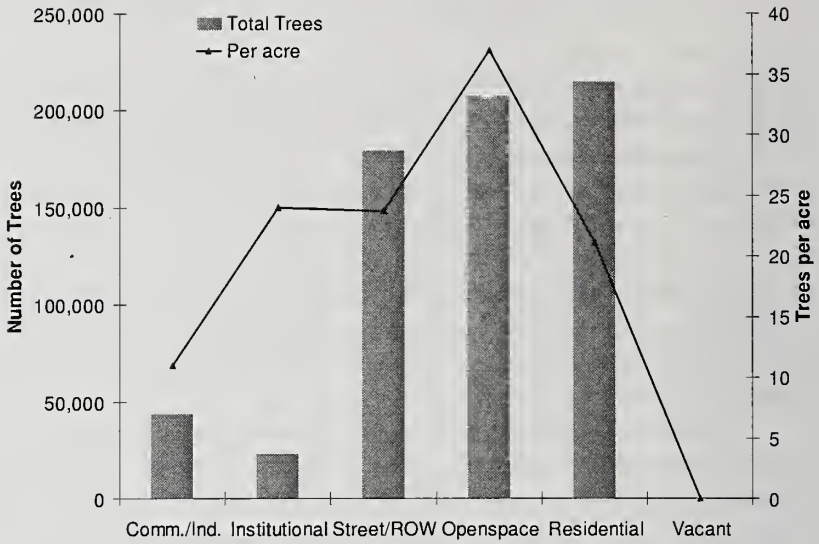
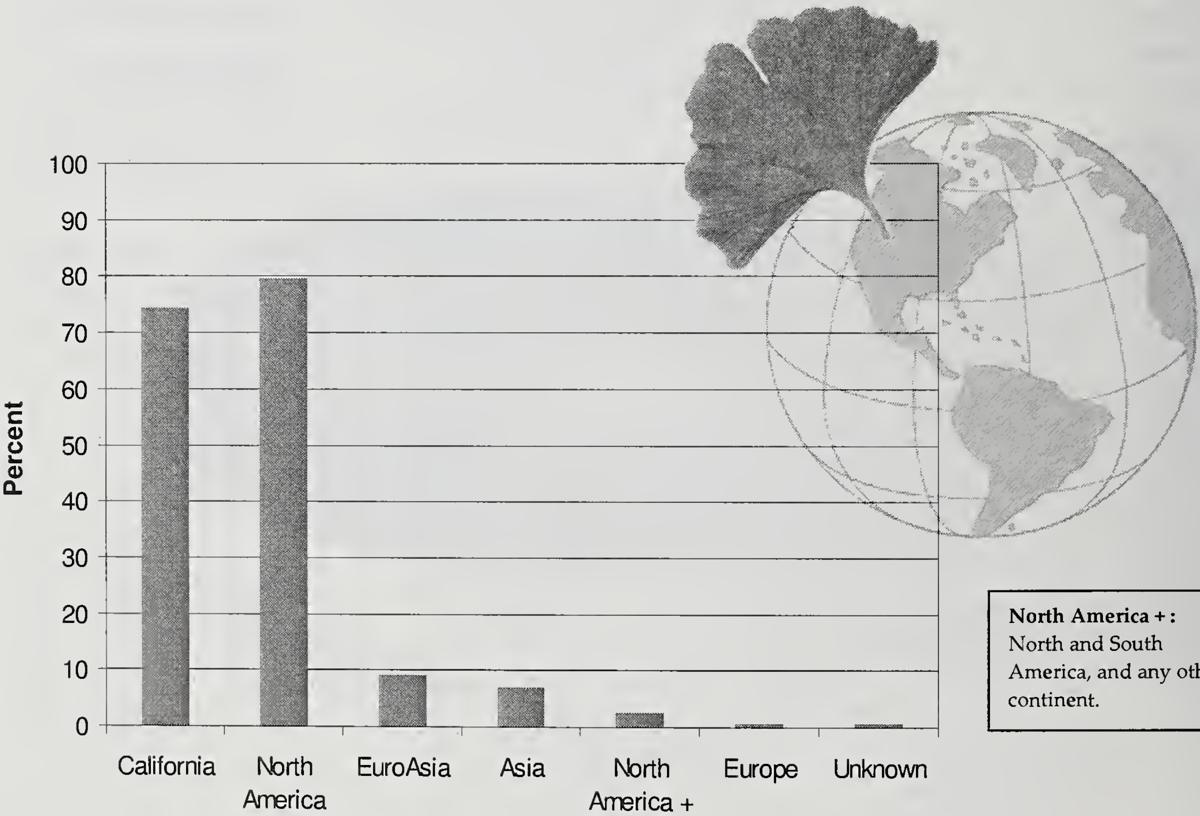


Figure 3. Number of trees & tree density by land-use types



North America + :
North and South America, and any other continent.

Figure 4. Percent of population by native range of species

Urban forest cover & leaf area

While trees cover approximately 11.9% of San Francisco, shrubs cover 6.9% of the city. Dominant ground cover types include herbaceous (e.g., grass, gardens) (34.0%), impervious surfaces (excluding buildings) (e.g., driveways, sidewalks, parking lots) (42.5%), and buildings (26.1%).

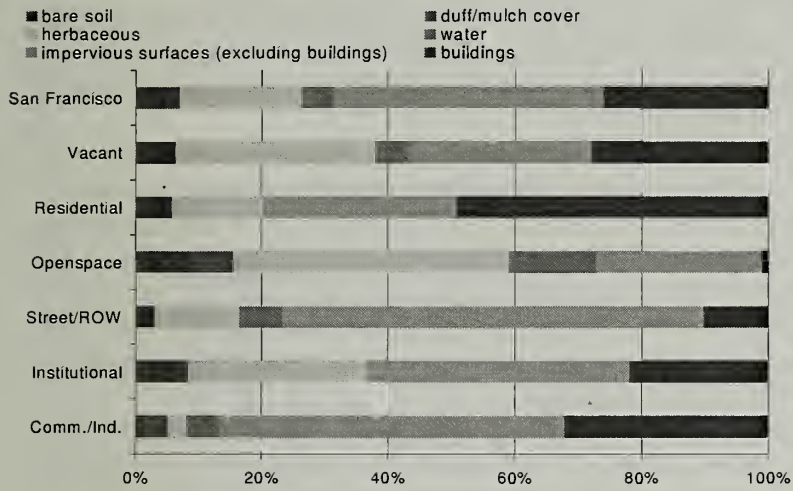


Figure 5. Ground cover distribution

Top ground covers:

1. herbaceous (34.0%)
2. impervious surfaces (excluding buildings) (42.5%)
3. buildings (26.1%)

Many tree benefits directly equate to the amount of healthy leaf surface area and size of the plant. Monterey cypress and blue gum eucalyptus dominate the leaf area of the city . Relatively large trees in the population (trees whose percent of canopy is greater than their percent of population) is dominated by Monterey ypress. Smaller trees in the population are blue gum eucalyptus, pittosporum, and olive.

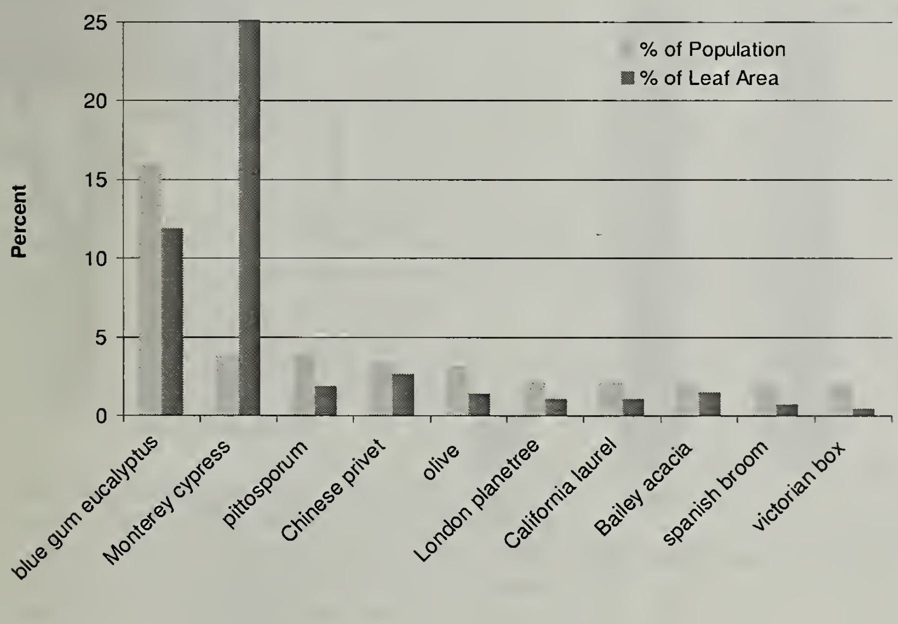


Figure 6. Percent of population & leaf area of ten most common species

The urban forest of San Francisco removes approximately 287 tons of pollutants each year, with a societal value of $1.3 million / year.

Air pollution removal by urban trees

Poor air quality is a common problem in many urban areas that leads to decreased human health, damage to landscape materials, ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing building energy use and consequent air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation[11].

Pollution removal by trees and shrubs in San Francisco was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for 2000. Pollution removal was greatest for ozone (O_3), followed by particulate matter less than ten microns (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). It is estimated that trees and shrubs remove 287 tons of air pollution (CO,NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $1.3 million (based on estimated national median externality costs associated with pollutants)[12]. Trees account for 54.2% of the removal.

Average percent air quality improvement during the daytime of the in-leaf season was 0.41% of O_3, 0.34% for PM10, 0.40% for SO_2, 0.24% for NO_2, and 0.00% for CO. In areas of 100% canopy cover, peak one-hour air quality improvements reached 11.9% of O_3, 9.3% for PM10, 12.3% for SO_2, 5.7% for NO_2 and 0.05% for CO.

General urban forest management recommendations to improve air quality are given in Appendix A.

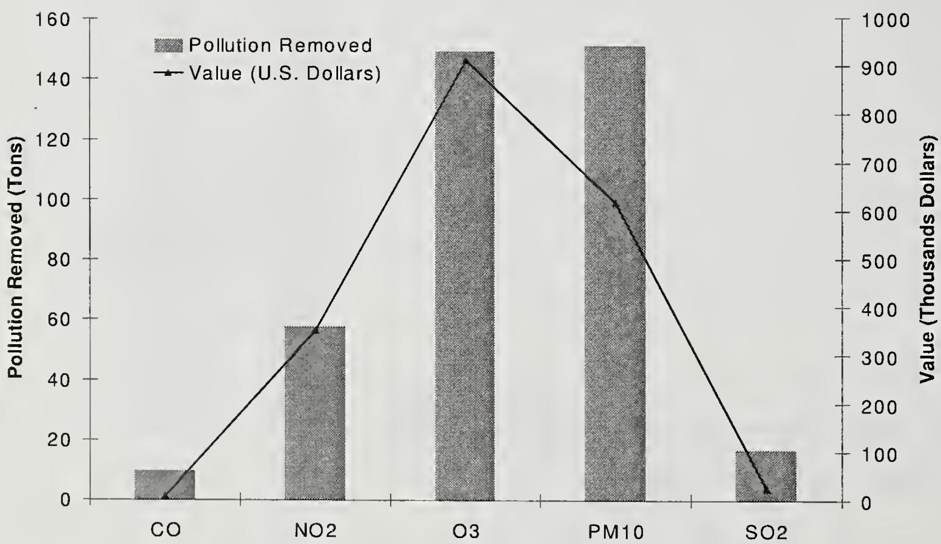


Figure 7. Annual pollution removal and value

Carbon storage and sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in their tissue as they grow, and by reducing building energy use and consequently carbon dioxide emissions from fossil-fuel based power plants[13].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Trees in San Francisco sequester about 5,100 tons of carbon per year with an associated value of $94,000.

Trees in San Francisco urban forest help to reduce atmospheric carbon by annually sequestering 5,100 tons of carbon.

The urban forest also current stores an additional 194,000 tons of carbon.

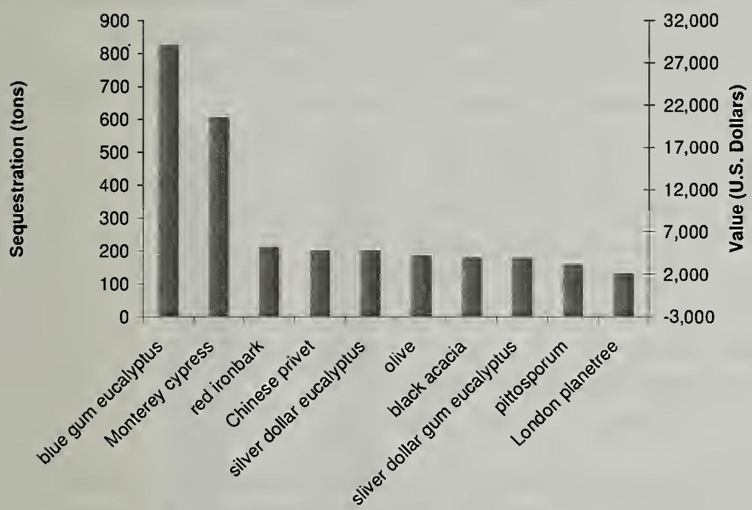


Figure 8 Carbon sequestration & value

Carbon storage by trees is another component to lessen global climate change. As trees grow they store more carbon and hold it within their tissues. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in San Francisco are estimated to store 194,000 tons of carbon ($3.6 million). Of all the species sampled, blue gum eucalyptus stores and sequesters the most carbon (approximately 27.1% of the total carbon stored and 19.0% of all sequestered carbon).

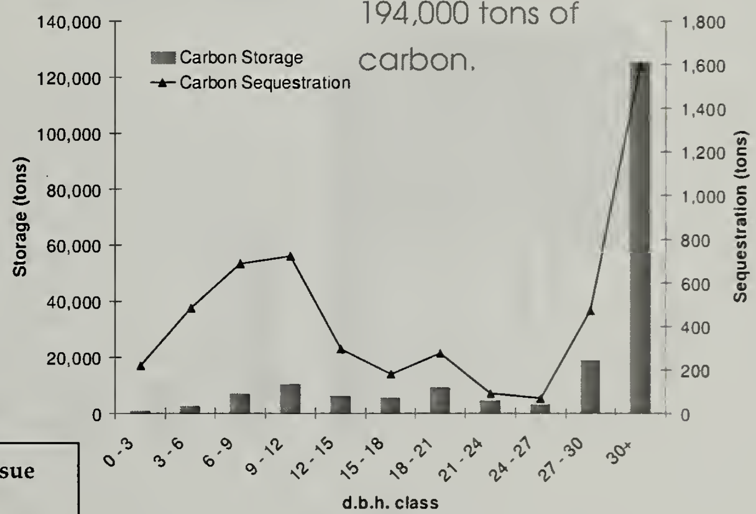


Figure 9. Carbon storage & sequestration by dbh class

Carbon storage – carbon currently held within tree tissue (roots, stems, and branches).

Carbon sequestration – estimate of carbon removed annually by trees. Net carbon sequestration can be negative (emission of carbon from decomposition) if forest is declining (i.e., release from decomposition greater than amount sequestered by healthy trees).

Monetary value

The structural value of the urban forest is estimated at $2 billion dollars.

Urban forests have a structural value based on the tree resource itself (e.g., the cost of having to replace the tree with a similar tree), and annually produce functional values (either positive or negative) based on the functions the tree performs. The structural value[9] of urban forest in San Francisco is approximately $2 billion. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees. Annual functional values also tend to increase with increased total number and size of healthy trees, and are usually valued on the order of several millions of dollars per year. Many more functional value of the urban forest exist, though they are not quantified here (e.g., reduction in air temperatures and ultra-violet radiation, improvements in water quality). Through proper and management urban forest values can be increased. However the values and benefits can also decrease as the amount of healthy tree cover declines.

<u>Structural values</u>:

- Structural value: **$2 billion**
- Carbon storage: **$3.6 million**
- Compensatory value: **$2 billion**

<u>Annual functional values</u>:

- Carbon sequestration: **$94,000**
- Pollution removal: **$1.3 million**

Additionally, information on other urban forest values can be found in Appendix B and information relating tree effects to other common objects can be found in Appendix C.

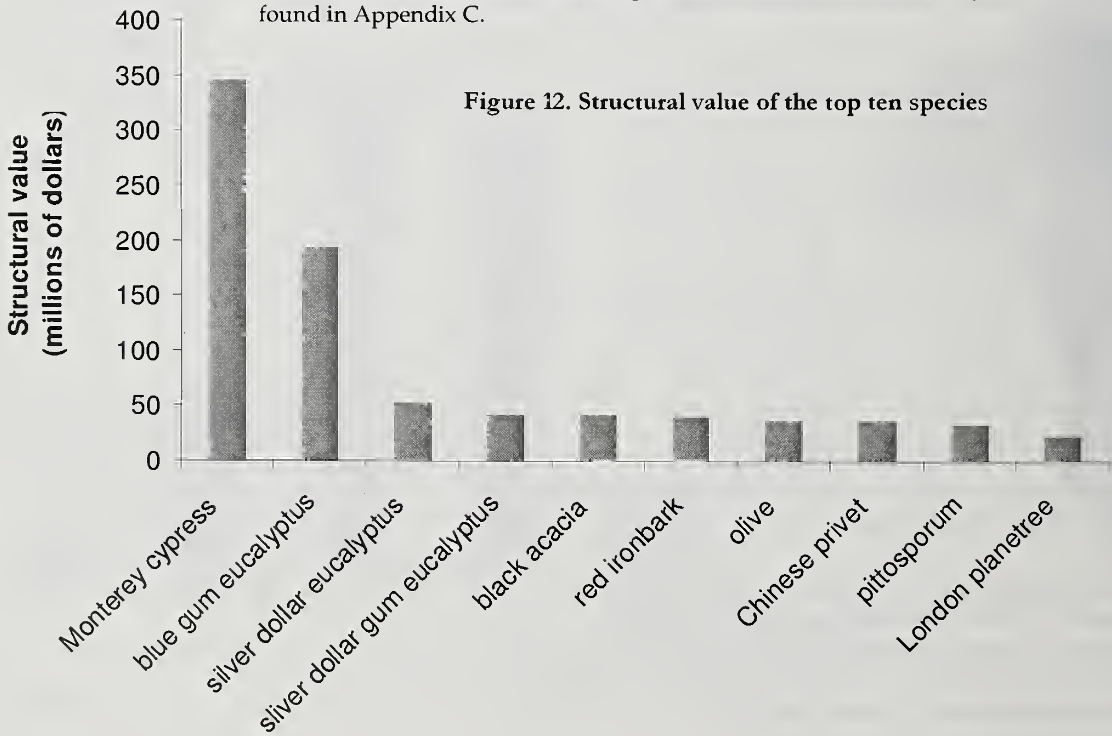


Figure 12. Structural value of the top ten species

Potential pest impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest resource. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential impact: Asian longhorned beetle, gypsy moth, emerald ash borer, and Dutch Elm Disease.

The Asian longhorned beetle (ALB)[14] is an insect that bores into and kills a wide range of hardwood species. The risk of ALB to the urban forest is a loss of $81 million in damage to the structural value (12.1% of the population).

Asian longhorned beetle

(Kenneth R. Law, USDA APHIS PPQ, www.invasive.org)

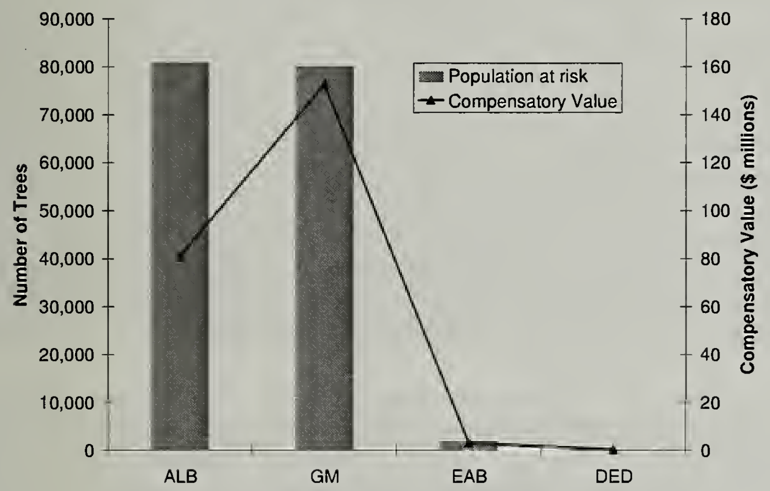


Figure 13. Potential pest impact

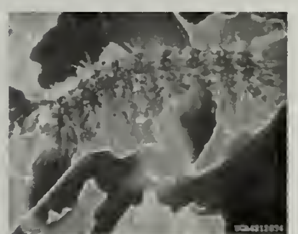
Emerald ash borer

(David Cappaert, Michigan State University, www.invasive.org)

The gypsy moth (GM)[15] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. The risk of this pest is a loss of $152 million in structural value (12.0% of the population).

Emerald ash borer (EAB)[16] is an insect that has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 0.3% of the population ($3 million in structural damage).

American elm, one of the most important street trees in the 20th century has been devastated by the Dutch elm disease (DED). Since being first reported in the 1930s it has killed over fifty percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, the tree population in San Francisco has a possibility to lose 0.0% of the total number of trees ($0 million in structural value).



Gypsy moth

(USDA Forest Service Archives, USDA Forest Service, www.invasive.org)

Appendix A. General recommendation of air quality improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. The four main ways that urban trees affect air quality are[17]:

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds (VOC) and tree maintenance emissions
Energy effects on buildings

The cumulative and interactive effects of trees on meteorology, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone are revealing that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities[11]. Local urban management decisions can also help improve air quality.

Urban forest management strategies to help improve air quality include[11]:

- Increase the number of healthy trees (increases pollution removal).
- Sustain existing tree cover (maintains pollution removal levels).
- Maximize use of low VOC emitting trees (reduces ozone and carbon monoxide formation).
- Sustain large, healthy trees (large trees have greatest per tree effects).
- Use long-lived trees (reduces long-term pollutant emissions from planting and removal).
- Use low maintenance trees (reduces pollutants emissions from maintenance activities).
- Reduce fossil fuel use in maintaining vegetation (reduces pollutant emissions).
- Plant trees in energy conserving locations (reduces pollutant emissions from power plants).
- Plant trees to shade parked cars (reduces vehicular VOC emissions).
- Supply ample water to vegetation (enhances pollution removal and temperature reduction).
- Plant trees in polluted areas or heavily populated areas (maximizes tree air quality benefits).
- Avoid pollutant sensitive species (increases tree health).
- Utilize evergreen trees for particulate matter reduction (year-round removal of particles).

Appendix B. Comparison of urban forests

A common question asked in viewing data from a city is "how does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals for trees

City	% Tree Cover	Number of trees Total	Carbon Storage (tons)	Carbon Sequestration (tons/yr)	Pollution removal (lbs/yr)	Pollution value U.S. Dollars
Calgary, Canada[a]	7.2	11,889,000	445,000	21,422	326,000	1,611,000
Atlanta, GA[b]	36.8	9,415,000	1,345,000	46,433	1,662,000	2,534,000
Toronto, Canada[c]	20.5	7,542,000	992,000	40,345	1,212,000	6,105,000
New York, NY[b]	21.0	5,212,000	1,351,000	42,283	1,677,000	8,071,000
Baltimore, MD[e]	21.0	2,627,000	596,000	16,127	430,000	2,129,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,115	576,000	2,826,000
Washington, DC[f]	28.6	1,928,000	523,000	16,148	418,000	1,956,000
Boston, MA[b]	22.3	1,183,000	319,000	10,509	284,000	1,426,000
Woodbridge, NJ[g]	29.5	986,000	160,000	5,561,	210,000	1,037,000
Minneapolis, MN[h]	26.5	979,000	250,000	8,895	305,000	1,527,000
Syracuse, NY[e]	23.1	876,000	173,000	5,425	109,000	268,000
Morgantown, WV[i]	35.9	661,000	94,000	2,940	66,000	311,000
Moorestown, NJ[g]	28.0	583,000	117,000	3,758	118,000	576,000
Jersey City, NJ[g]	11.5	136,000	21,000	890	41,000	196,000
Freehold, NJ[g]	34.4	48,000	20,000	545	21,000	133,000

II. Total per acre for trees

City	Trees	Carbon Storage (tons)	Carbon Sequestration (lbs/yr)	Pollution removal (lbs/yr)	Pollution value U.S. Dollars
Calgary, Canada[a]	66.7	2.5	120.2	1.8	9.0
Atlanta, GA[b]	111.6	15.9	550.4	19.7	30.0
Toronto, Canada[c]	48.3	6.4	258.3	7.8	39.1
New York, NY[b]	26.4	6.8	214.1	8.5	40.9
Baltimore, MD[e]	50.8	11.5	312.0	8.3	41.2
Philadelphia, PA[b]	25.0	6.3	190.9	6.8	33.5
Washington, DC[f]	49.0	13.3	410.6	10.6	49.7
Boston, MA[b]	33.5	9.0	297.8	8.0	40.4
Woodbridge, NJ[g]	66.5	10.8	375.3	14.2	70.0
Minneapolis, MN[h]	26.2	6.7	238.2	8.2	40.9
Syracuse, NY[e]	54.5	10.8	337.7	6.8	16.7
Morgantown, WV[i]	119.7	17.0	532.3	11.9	56.3
Moorestown, NJ[g]	62.0	12.5	399.9	12.6	61.3
Jersey City, NJ[g]	14.3	2.2	93.9	4.3	20.7
Freehold, NJ[g]	38.5	16.0	436.8	16.8	106.6

<u>Data collection group</u>

a City personnel
b ACRT, Inc.
c University of Toronto
d US Forest Service & Institute of Tropical Forestry
e US Forest Service
f Casey Trees Endowment Fund
g New Jersey Department of Environmental Protection
h Davey Resource Group
i West Virginia University

Appendix C. Relative tree effects

This appendix details some information about the urban forest in San Francisco. It details general tree information and compares forest effects to average carbon emissions in city[18], average passenger automobile emissions[19], and average household emissions[20].

General tree information:

Average tree diameter (dbh) = 10.1 in.
Median tree diameter (dbh) = 5.8 in.
Average number of trees per person = 0.9 trees
Number of trees sampled = 278
Number of species sampled = 41

Average tree effects by tree diameter:

DBH Class	Carbon Storage (lbs)	($)	(miles)	Carbon Sequestration (lbs/yr)	($/yr)	(miles)	Pollution Removal (lbs)	($)
1-3	7	0.07	30	2.1	0.02	8	0.1	0.13
3-6	38	0.35	140	7.2	0.07	26	0.2	0.37
6-9	125	1.15	460	12.1	0.11	44	0.4	0.88
9-12	283	2.61	1,040	19.9	0.18	73	0.4	0.91
12-15	435	4.00	1,590	20.7	0.19	76	0.8	1.71
15-18	795	7.32	2,910	25.7	0.24	94	1.0	2.29
18-21	981	9.04	3,590	28.9	0.27	106	0.7	1.65
21-24	1,376	12.67	5,040	26.8	0.25	98	0.6	1.34
24-27	1,431	13.18	5,240	30.8	0.28	113	1.3	2.95
27-30	2,588	23.84	9,480	64.4	0.59	236	0.6	1.32
30+	4,959	45.67	18,160	63.2	0.58	231	2.0	4.57

(miles = number of auto miles driven that produces emissions equivalent to tree effect)

Carbon storage is equivalent to:

Amount of carbon emitted in city in 31 days or
Annual carbon (C) emissions from 116,000 automobiles or
Annual C emissions from 58,500 single family houses

Annual carbon sequestration is equivalent to:

Amount of carbon emitted in city in 0.8 days or
Annual C emissions from 3,100 automobiles or
Annual C emissions from 1,500 single family homes

Carbon monoxide removal is equivalent to:

Annual carbon monoxide emissions from 30 automobiles or
Annual carbon monoxide emissions from 100 single family houses

Nitrogen dioxide removal is equivalent to:

Annual nitrogen dioxide emissions from 1,700 automobiles or
Annual nitrogen dioxide emissions from 1,100 single family houses

Sulfur dioxide removal is equivalent to:

Annual sulfur dioxide emissions from 11,600 automobiles or
Annual sulfur dioxide emissions from 200 single family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:

Annual PM10 emissions from 123,500 automobiles or
Annual PM10 emissions from 11,900 single family houses

Appendix D. List of species sampled in San Francisco

				Susceptible to Pest			
Common Name	**Genus**	**Species**	**% Population**	**ALB**	**GM**	**EAB**	**DED**
grand fir	Abies	grandis	0.3				
Bailey acacia	Acacia	baileyana	1.9				
silver wattle	Acacia	dealbata	0.3				
Sydney golden wattle	Acacia	longifolia	0.1				
black acacia	Acacia	melanoxylon	1.8				
acacia	Acacia	species	0.4				
Japanese maple	Acer	palmatum	1.1	🌲			
strawberry tree	Arbutus	unedo	0.6				
paper birch	Betula	papyrifera	0.5	🌲			
common boxwood	Buxus	sempervirens	0.3				
bottlebrush	Callistemon	pendula	0.5				
camellia	Camellia	species	1				
algarrobo europeo	Ceratonia	siliqua	0.3				
lime	Citrus	aurantifolia	0.3				
lemon	Citrus	limon	0.8				
cordyline	Cordyline	australis	0.4				
gray dogwood	Cornus	racemosa	1.1				
cotoneaster	Cotoneaster	species	0.8				
English hawthorne	Crataegus	oxyacantha	0.3		🌲		
Washington hawthorn	Crataegus	phaenopyrum	0.4		🌲		
carrotwood	Cupaniopsis	anacardioides	0.8				
Monterey cypress	Cupressus	macrocarpa	3.8				
tree-fern	Cyathea	arborea	1.2				
hop bush, hopseed bush	Dodonaea	viscosa	0.5				
dracaena	Dracaena	marginata	0.3				
silver dollar eucalyptus	Eucalyptus	cinerea	1.3		🌲		
ed-flowering gum	Eucalyptus	ficifolia	0.4		🌲		

Common Name	Genus	Species	% Population	ALB	GM	EAB	DED
blue gum eucalyptus	Eucalyptus	globulus	15.9		🌲		
sliver dollar gum eucalyptus	Eucalyptus	polyanthemos	0.8		🌲		
red ironbark	Eucalyptus	sideroxylon	1.3		🌲		
eucalyptus	Eucalyptus	species	0.1		🌲		
common fig	Ficus	carica	1				
ficus macrocarpa	Ficus	macrocarpa	0.4				
ficus microcarpa	Ficus	microcarpa	1.6				
Indian laurel fig	Ficus	nitida	0.1				
caucasian ash	Fraxinus	oxycarpa	0.3	🌲		🌲	
fuchsia	Fuchsia	species	0.3				
Australian willow, wilga	Geijera	parviflora	0.4				
ginkgo	Ginkgo	biloba	0.4				
honeylocust	Gleditsia	triacanthos	0.3				
christmasberry	Heteromeles	arbutifolia	0.1				
English holly	Ilex	aquifolium	0.3				
holly	Ilex	species	0.3				
jacaranda	Jacaranda	acutifolia	0.6				
juniper	Juniperus	species	1.2				
Japanese larch	Larix	leptolepis	0.1				
laurel de olor	Laurus	nobilis	0.5				
mallow	Lavatera	arborea	0.3				
Australian tea tree	Leptospermum	laevigatum	0.1				
Chinese privet	Ligustrum	lucidum	3.2				
privet	Ligustrum	species	1.6				
southern magnolia	Magnolia	grandiflora	1.1				
magnolia	Magnolia	species	0.1				
saucer magnolia	Magnolia	x soulangeana	0.1				
crabapple	Malus	species	0.3	🌲	🌲		
apple	Malus	sylvestris	1.6	🌲	🌲		
wild dilly	Manikara	bahamensis	0.4				
mayten	Maytenus	boaria	0.9				
cajeput tree	Melaleuca	quinquenervia	0.7				

Common Name	Genus	Species	% Population	ALB	GM	EAB	DED
michelia	Michelia	doltsopa	0.3				
mioporo	Myoporum	laetum	1.6				
olive	Olea	europaea	3.1				
other species	Other	species	0.8				
palm	Palm	species	0.3				
avocado	Persea	americana	0.7				
raser photinia	Photinia	xfraseri	0.3				
tailian stone pine	Pinus	pinea	0.3				
Monterey pine	Pinus	radiata	8.4				
ed pine	Pinus	resinosa	0.3				
pine	Pinus	species	0.3				
pittosporum	Pittosporum	species	3.8				
pittosporum	Pittosporum	species	0.5				
lapanese pittosporum	Pittosporum	tobira	0.3				
ictorian box	Pittosporum	undulatum	1.9				
ondon planetree	Platanus	acerifolia	2.1	🌲			
ern pine	Podocarpus	gracilior	0.5				
apricot	Prunus	armeniaca	0.3	🌲	🌲		
cherry plum	Prunus	cerasifera	1.1	🌲	🌲		
ciruelo rojo	Prunus	cerasifera var. nig	0.3	🌲	🌲		
common plum	Prunus	domestica	0.7	🌲	🌲		
common cherry laurel	Prunus	laurocerasus	0.8	🌲	🌲		
Portugal laurel	Prunus	lusitanica	0.5	🌲	🌲		
nectarine	Prunus	persica	0.5	🌲	🌲		
wanzan cherry	Prunus	serrulata	0.8	🌲	🌲		
cherry	Prunus	species	0.5	🌲	🌲		
rethorn	Pyracantha	species	0.3				
evergreen pear	Pyrus	kawakamii	0.9	🌲			
oast live oak	Quercus	agrifolia	0.1	🌲	🌲		
ak	Quercus	species	0.5	🌲	🌲		
ndia hawthorn	Raphiolepis	indica	0.8				
umac	Rhus	species	0.4				

Common Name	Genus	Species	% Population	ALB	GM	EAB	DEI
cabbage palmetto	Sabal	palmetto	0.9				
spanish broom	Spartium	junceum	1.9				
English yew	Taxus	baccata	0.8				
yew	Taxus	species	0.3				
almendra	Terminalina	catappa	0.1				
windmill palm	Trachycarpus	fortunei	0.4				
Brisbane box	Tristania	conferta	1.1				
California laurel	Umbellularia	californica	2.1				
California palm	Washingtonia	filifera	0.6				
Mexican fan palm	Washingtonia	robusta	0.3				
aloe yucca	Yucca	aloifolia	0.4				

ALB = Asian longhorned beetle; GN = gypsy moth; EAB = emerald ash borer; DED = Dutch elm disease

References

1 – Nowak, D.J., and D.E. Crane. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions. In: Hansen, M. and T. Burk (Eds.) *Integrated Tools for Natural Resources Inventories in the 21st Century*. Proc. Of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720.

2 – The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such does not constitute an official endorsement or approval by the United States Department of Agriculture or Forest Service of any product or service to the exclusion of others that may be suitable.

The USDA Forest Service provides urban forest analyses through the UFORE model, which has internal quality control checks. However, the quality assurance of the data collection is the responsibility of the data collection group. Quality assurance guidelines are suggested, but checks of data inputs and measurement procedures (e.g., were the species identified correctly, were measures made correctly) are dependent upon adequate training and oversight by the data collection group. As these parts of the data collection process are out of the control of the USDA Forest Service, there is no implied or expressed quality assurance of the data collected. The results presented in this report are based on the data supplied by the local data collection group.

3 – see UFORE field manual: http://www.fs.fed.us/ne/syracuse/Tools/downloads/UFORE_Manual.pdf

4 – Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. *Gen. Tech. Rep. NE-186*. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.

5 – Baldocchi, D. 1988. A multi-layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy. *Atmospheric Environment*. 22: 869-884; Baldocchi, D.D.; Hicks, B.B.; Camara, P. 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. *Atmospheric Environment*. 21: 91-101.

6 – Bidwell, R.G.S.; Fraser, D.E. 1972. Carbon monoxide uptake and metabolism by leaves. *Canadian Journal of Botany*. 50: 1435-1439; Lovett, G.M. 1994. Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective. *Ecological Applications*. 4: 629-650.

7 – Zinke, P.J. 1967. Forest interception studies in the United States. In: Sopper, W.E.; Lull, H.W., eds. *Forest Hydrology*. Oxford, UK: Pergamon Press: 137-161.

8 – based on: McPherson, E.G. and J. R. Simpson 1999. Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters. *USDA Forest Service, Gen. Tech. Rep. PSW-171* 237 p. http://wcufre.ucdavis.edu/products/cufr_43.pdf

9 – based on Council of Tree and Landscape Appraisers guidelines. For more information, see Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002. Compensatory value of urban trees in the United States. *J. Arboric.* 28(4): 194-199.

10 – for detailed methods, see: Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra. 2002. Brooklyn's Urban Forest. *Gen. Tech. Rep. NE-290*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

11 – for more information, visit: http://www.fs.fed.us/ne/syracuse/TREE%20Air%20Qual.pdf

12 – Murray, F.J.; Marsh L.; Bradford, P.A. 1994. New York State Energy Plan, vol. II: issue reports. Albany, NY: New York State Energy Office.

13 – for more information, see: Abdollahi, K.K., Z.H. Ning, and A. Appeaning (eds). 2000. *Global climate change and the urban forest*. GCRCC and Franklin Press, Baton Rouge, LA.

14 – For more information, visit: http://www.na.fs.fed.us/spfo/alb/

15 – For more information, visit: http://na.fs.fed.us/wv/gmdigest/

16 – For more information, visit: http://www.na.fs.fed.us/spfo/eab/index.html

17 – Nowak, D.J.. 1995. Trees pollute? A "TREE" explains it all, in: Proc. 7th Natl. Urban For. Conf., (C. Kollin and M. Barratt, eds.), American Forests, Washington, DC, pp. 28-30.

18 – Total city carbon emissions were based on 2003 U.S. per capita carbon emissions – calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/ggrpt/) divided by 2003 U.S. total population (www.census.gov). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

19 – Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/). Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/). Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO_2 Emissions. Climatic Change 22:223-238.

20 – Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from Energy Information Administration Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001 www.eia.doe.gov/emeu/recs/contents.html. CO_2, SO_2, and NO_x power plant emission per KWh from U.S. EPA U.S. Power Plant Emissions Total by Year www.epa.gov/cleanenergy/egrid/samples.htm. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration. 1994 Energy Use and Carbon Emissions: Non-OECD Countries DOE/EIA-0579 report that states that about one percent of carbon total emissions from electricity generation are in the form of ash, carbon monoxide, and volatile organic compounds. PM10 emission per kWh from Layton, M. 2004. 2005 Electricity Environmental Performance Report: Electricity Generation and Air Emissions. California Energy Commission. http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF CO2, NOx, SO2, PM10, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Abraxas energy consulting http://www.abraxasenergy.com/emissions/ CO2 and fine particle emissions per Btu of wood from Houck, J.E. Tiegs, P.E, McCrillis, R.C. Keithley, C. and Crouch, J. 1998. Air emissions from residential heating: the wood heating option put into environmental perspective. Proc. of USEPA and Air Waste Management Association Conf: Living in a Global Environment, V.1: 373-384. CO, NOx and SOx emission per Btu based on total emissions and wood burning (tonnes) from Residential Wood Burning Emissions in British Columbia, 2005. wlapwww.gov.bc.ca/air/airquality/pdfs/wood_emissions.pdf. Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from Heating with Wood I. Species characteristics and volumes. http://ianrpubs.unl.edu/forestry/g881.htm

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

"Caring for the Land and Serving People through Research"